Investigation the influence of composition and shape on briquettes compression strength

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Abstract
The article is devoted to the investigation of the possibility of using liquid carbonaceous wastes of PJSC "ArcelorMittal Kryvyi Rih" as a binder for coke breeze briquetting. The results of physical and chemical analysis of coke production waste are presented in this work. In laboratory conditions the effect of the composition and form on briquettes strength were determined, as well as the optimal parameters of briquetting process.
Key words: COKE BREEZE, TAR DECANTER SLUDGE, BRIQUETTING, COMPRESSIVE STRENGTH, BINDER, PRESSURE

Introduction

A rapid development of market economy increases active consumption of energy resources that inevitably leads to the creation of energy-efficient technologies for complex use of raw materials with a maximum reduction of harmful effect on the environment. The problem of rational waste utilization is becoming more relevant in different branches of industry in Ukraine, especially in mining, metallurgical and coal. Returning wastes to technological processes not only solves the problem of resource saving, but also improves the environmental situation at enterprise. Due to the great number of fine fractions of industrial waste an interest in their reuse has significantly increased. Developed technologies for waste processing should correspond to the methods of their further use to ensure consumer properties of products. The main direction of domestic and foreign enterprises researches is focused on utilizing the wastes in its own production. Some of Ukrainian industrial plants have been investigation it, such as PJSC "ArcelorMittal Kryvyi Rih", JSC "Azovstal iron & steel works", PJSC "Nikopol Ferroalloys Plant". In solving a wide range of problems of waste recycling process, its efficiency and profitability, a comprehensive approach for their solution is necessary. Especially it is important for large-scale industrial enterprises, first of all, for the enterprises with full metallurgical cycle. A comprehensive approach should involve consideration of the collecting, transportation, accumulation, storage and recycling wastes as one [1].

A brief review of publications on the subject

There are a lot of publications on utilization of fine fraction metallurgical wastes. Waste briquetting technology is most successfully used by USA, Great Britain, Germany, France, Japan, Poland. One of the founders of the theory and practice of briquetting can be considered Frank G. and Kegel K. from Germany [2]. Kegel has determined laws of influence of the charge humidity on the strength of fuel briquettes. In Germany one of the researchers of the processes of briquetting is Professor Wolfgang [3], the continuous research in this area are carried out at the Technical University of Freiberg University of Mining and Technology. The first research on coke breeze briquetting was conducted by Belke W. E. and was published in form of thesis. Somchai O., Kunchana B. have conducted research on creation of coal briquettes with lime as organic binder. During their research they proved not only the ability to create stable briquettes, but also their desulphurization that significantly reduced the impact of these briquettes on the environment while burning. Novik G. studied method of coke briquettes from coke dust and liquid petroleum bitumen with addition of carbide powder and spent sulfite-alcohol liquor [4]. Luriy V. proposed method of coke briquettes that are called «KOKS-BRIK». The method consists of mixing coke breeze and 1-3 wt. % of binding reagent sulfonic acid, briquetting the mixture and then heat treatment at 200 - 700 °C for 10-120 minutes [5].

The solution to this problem at the Ukrainian enterprises are carried out by means of research and project-design organizations that have some experience in the development of technology and equipment for briquetting. These organizations include the Institute of Ferrous Metallurgy of National Academy of Sciences of Ukraine and the NPP «ECOTOM» (Dnepropetrovsk), Mechanobrchermet (Kryvyi Rih), DonNII Chermet NGO «Incor» (Donetsk), Giprostal (Kharkiv). For example for PJSC "Azovstal Iron & Steel Works" research work on the development of technology and press equipment for briquetting carbonaceous wastes has been done. For PJSC "Dnepropetrovsk Rolling Rolls Plant" technology for briquetting cast iron chips has been developed. Iron and Steel Institute analyzed all kinds of waste generated in the Nikopol ferroalloy plant in terms of possibility and feasibility of briquettes production [1,6-10].

The goal

To investigate physical and chemical properties of coke wastes. Taking into account the obtained data to determine the method of waste recycling, as well as the possibility of their return to the technological process of the enterprise considering economic expediency.

Materials and methods

Coke plant wastes from PJSC "ArcelorMittal Kryvyi Rih": coal fines, coke breeze, tar decanter sludge were collected for chemical and physical analysis. In laboratory conditions briquetting is performed on hydraulic press PSU-250. The compressive strength was measured by placing briquettes on metal plate assembled on press and increasing the pressure. The pressure value was recorded by load cell that allows to detected the maximum pressure after which the briquette was crushed.

Results and discussion

Metallurgical enterprises are inextricably linked to the production of coke. One of the main wastes of coke production is coke breeze and coal dust. Coke breeze is generated in technological operations that connected to coke production (coke sorting, quenching of coke, coke transporting, etc.). There is a difficulty in coke breeze application because of loading and transportation issues. It is rarely processed on the plant itself mostly because of the lack of technology that is not provided by the original project; therefore the utilization process of these wastes is mainly burning. This method of recycling vastly decreases its potential as a by-product that can be reused. Three samples were taken for chemical analysis: the first one from coke sorting and the other from decanters after wet quenching (Table 1.1).

Table 1.1. Chemical composition of coke breeze

№ of samples	C	S	P	Fe	SiO_2	CaO	MgO	Al_2O_3
1	85,6	0,67	0,049	1,56	6,3	0,7	0,34	3,87
2	84,3	0.65	0,051	1,57	6,1	0,56	0.44	3.56
3	83,5	0,67	0,048	1,44	6,4	0,67	0,32	3,34

There is a classification of coke breeze considering ash content: CB-1 with A_d=13%, W_a=10-13%; CB-2 with A_d=16%, W_a=13-16%; CB-3 with A_d=18%, W_a = 16-22% (Table 1.2). The research was carried out with low ash content coke breeze of mark CB-1

Table 1.2. Technical analysis of coke breeze samples

№ of samples	W_a, wt%	V_{daf}, wt%	A_d, wt%	S^d_t, wt%	Q, MJ/kg	Mechanical properties, %		
						M40	M25	M10
1	13,2	1,87	13,2	0,4	26,1	71,1	87	6,9
2	12,2	2,21	14,4	0,67	23,3	64,3	78	8,5
3	14.8	2,56	13,8	0,81	21,7	65,2	81	9,8

Investigating the world experience in coke breeze recycling it can be concluded that most of the technologies are associated with different coke breeze compacting methods. One of the most important parameters are economic efficiency of the process, type of the binder used, its cost, power consumption and other expenses to implement new way of waste utilization [7-12]. An aim of analysis of utilization and recycling techniques has been carried out to find a suitable process that fits into technical scheme of coke production.

Currently, there are several methods for processing of coke breeze in a solid commercial product: granulation, briquetting and pelletizing.

Agglomeration - the process of obtaining pieces (agglomerate) of fine particles by sintering method. After coal particles are agglomerated they are separated with a help of sieve. Agglomeration of fine coal has many advantages over the other processing technologies, and for this reason a number of coal preparation processes were developed: the Trent process, the Convertol process, the spherical agglomeration process and the Otisca-T process [13]

Granulation is a process of agglomeration of finely divided materials based on their ability to form spherically shaped granules (pellets) by rolling. The formation of the pellets due to the action of chemical and physical forces. The most important properties of the raw materials in the granulation are humidity (8 to 20% depending on the type of material), the grinding particle size (0,044-0,074 mm), binders and additives [13,14].

Briquetting is a process of mechanical processing of coal fines in the lump fuel - briquettes with certain geometrical shape, size and weight. Briquetting process can be accomplished at compaction pressures of 15.0 to 200.0 MPa - less sensitive to the properties of feedstock, and therefore is used for processing of various grained materials of dispersion up to 10 mm. Briquetting of fine-dispersed materials is carried out without a binder at compaction pressure greater than 75 MPa, and with the addition of binder at pressures typically around 15 to 50 MPa. The process of briquetting is strongly influenced by the composition, moisture content and particle size of the material, temperature, surface pressure and duration of pressing [12-15].

The purpose of compacting of coke breeze is not only to receive pieces of a predetermined size, but also to create a briquette complex of composite mixtures with tailored physico-chemical properties to ensure the quality depending on the application. Accordingly, there is a relationship of technological parameters of the densification process with the qualitative characteristics of coke breeze.

There are a large variety of pressing equipment for briquetting of industrial and raw materials. They can be classified into periodic and continuous operation type. Selection of equipment is determined by the properties of the waste and the required pressure of pressing. Screw extrusion low-pressure press is economical, but it is mainly used for briquetting of biomass; roller press is medium pressure and suitable for hard coals and fine coal waste; ram press is suitable for brown coal and has a relatively high level of energy consumption. The main technical characteristics of the presses are: capacity, pressure, power consumption, weight and parameters of equipment.

Thus briquetting of coke breeze is the most universal method of involving it in processing, also as a binder may be used a number of industrial waste, reducing the cost of briquetting process. The main requirements for the raw material mixture for the production of briquettes are particle size distribution of waste and binder cost, the optimum in terms of the required strength. A significant role is also played by physical and chemical composition of a fine-dispersed waste and binder used in briquetting. In addition, the briquette should meet the following requirements: - should not contain harmful impurities for coking process above acceptable levels; - has sufficient strength for its further transportation; - to retain strength at high humidity; - has a homogeneous chemical composition; - has sufficient strength at high temperatures; - has an optimal size and shape;

- has a low cost.

The main factor in selecting the optimal particle size of waste for the production of briquettes is to provide the most compact packaging with a minimum of voids and cavities in which are provided the greatest strength of the contacts between the grains and the high strength of the briquettes and low consumption of binder. Particle size, providing maximum compaction according to formula Fuller and Thompson presented in Table 1.3 Particle size distribution was obtained by sieve analysis.

Table 1.3. Particle size of coke breeze

№ of samples	<1 mm	1-3 mm	3-5 mm	5-8 mm	8-10 mm
1	3.5	12.7	30.6	42.5	10.7
2	3.7	10.2	28.9	45.6	11.6
3	4.1	11.3	34.1	41.3	9.2

The correct choice of binder in the development of new technological processes of briquetting is of great importance. Due to the increased popularity of using a variety of pitches, from the waste they have turned into a saleable material, which has a high price, so the question is finding other effective, non-toxic, cheap and abundant materials with adhesive properties.

For a targeted selection of briquette binders and technology of their preparation is necessary to consider the basic chemical and structural features of binders, defining the scope of their application. Common binders that are used for coal briquetting are: coal tar pitch (a residue of coking process); petroleum bitumen (refining process); molasses with addition of lime or phosphoric acid; starch (wood processing industry); lignosulphonate (paper industry).

A binder for the experiment was chosen among the wastes that are abundant at coke plant. A number of laboratory studies were carried out with tar decanter sludge to determine its influence on briquette structure and strength.

Coke oven gas contains a lot of organic compounds. It is generated as by-product of coke making process. Coal tar is one of these compounds, which is collected and passed to a tar decanter tank. Tar sludge accumulates at the bottom of the tanks by gravity separation. It is removed using a scraper conveyor and collected in a sludge pot. Tar sludge is a thick mass that hardens at 0 °C. But heating to 80-90 °C sludge slightly softens increasing the fluidity.

The total content of the solid phase in tar sludge is 40-50%, the rest is coal tar. The carbon content of sludge is 60-55% by weight, volatile – 50-40% by weight, the highest specific heat of combustion - 35-33 MJ/kg. The composition of the solid and plastic phase of sludge is not constant and varied depending on different coke oven exploitation conditions (see Table 1.4).

Table 1.4. Main components of coke sludge

Component	Content of component in coke sludge, % by weight
Ash	1,2-2,6
Iron	1-2
Sulfur	3-6
Cyanogen	0,5-1
Soluble in toluene substances	35-39

The goal of this study is to determine an impact of composition and size on briquette strength. In the experiment four samples were prepared with different ratio of components. The binder, coke breeze and fines were heated to 90°C and thoroughly mixed that allowed to lower the viscosity of the binder and improved its distribution between particles to form a thin layer. The blend was put in molds with a diameter of 29 mm and briquetted with a pressure of 350 kg/cm^2 with time dwell 3-5 minutes and then increasing the pressure up to 500 kg/cm^2. After that green briquettes were cured for 8-10 minutes at 100 °C in the absence of air. Four samples were prepared (Table 1.5); each had variation of briquettes with the original weight of mix 8 g, 12 g, 16 g, 20 g, 24 g and 28 g which resulted in different length (Table 1.6). The compressive strength was measured after cooling briquettes to the room temperature.

The strength is indicated as surface (axially vertical) compression in which the briquette is inserted between two plates pressing machine with crosshead speed of 1mm/min.

Table 1.5. Composition of briquettes

№ of sample	Coke breeze, %	Coal fines, %	Tar sludge, %
1	91	1	8
2	89	1	10
3	87	1	12
4	85	1	14

Table 1.6. Physical parameters of briquettes

№ of experiment	Briquette dimension				Compressive strength, kg/cm^2
	Weight, g	Length, mm	Diameter, mm	L/D ratio	
Sample 1					
1	8	10	29	0.34	48.2
2	12	15.5	29	0.53	49.7
3	16	21.2	29	0.74	50.3
4	20	26.5	29	0.91	51.8
5	24	32	29	1.08	50.1
6	28	37.5	29	1.29	48.4
Sample 2					
1	8	10	29	0.34	50.2
2	12	15.5	29	0.53	52.8
3	16	21.2	29	0.74	53.1
4	20	26.5	29	0.91	55.3
5	24	32	29	1.08	53.6
6	28	37.5	29	1.29	51.8
Sample 3					
1	8	10	29	0.34	40.6
2	12	15.5	29	0.53	42.5
3	16	21.2	29	0.74	43.1
4	20	26.5	29	0.91	45.2
5	24	32	29	1.08	43.4
6	28	37.5	29	1.29	39.1
Sample 4					
1	8	10	29	0.34	39.1
2	12	15.5	29	0.53	41.8
3	16	21.2	29	0.74	42.6
4	20	26.5	29	0.91	44.5
5	24	32	29	1.08	42.8
6	28	37.5	29	1.29	40.1

After conducting research it can be seen that briquettes with a weight of 20 g gave a better compressive strength as compared to other experiments in all four samples. The optimal L/D ratio of briquettes is 0.91. The compressive strength was increased in the second sample but decreased in the third and fourth, therefore the second sample with 89% of coke breeze the briquette varying from 50.2 to 55.3 kg/cm^2. In the next experiment t and 10% of binder had the best composition in terms of right combination of components with strength of he L/D ratio of 0.91 and weight of 20 g were kept as constant and the percentage of coal fines was increased (5, 8, 11, 14) to investigate its impact on briquette strength.

Table 1.7. Physical properties of briquettes with different percentage of coal fines

№ of sample	Briquette dimension			Compressive strength, kg/cm^2
	Weight, g	L/D ratio	Coal fines, %	
1	20	0.91	5	58.4

2	20	0.91	8	59.6
3	20	0.91	11	63.2
4	20	0.91	14	58.5

The table 1.7 shows the result and it can be observed that briquettes with 11% of coal fines lead to the best compressive strength throughout the whole research 63.2 kg/cm^2.

Conclusion

The possibility of using coke production waste to create briquettes was considered in this paper. An optimal composition of briquettes, briquetting parameters and conditions of isothermal heat treatment was experimentally determined.

Also the effect of length diameter ratio was studied and the following conclusion can be made. In all experiments the compressive strength of briquettes increased to a certain point (with L/D ratio 0.91) but after reaching its maximum in the 4th experiment the compressive strength of briquettes starts to decrease. Therefore the optimal ratio in this study and for this particular composition of wastes is 0.91.

The amount of coal fines 11% gave the highest strength comparing to other samples. Briquettes from coke breeze, coke dust and tar decanter sludge with a maximum compressive strength of 63.2 kg/cm^2 have been obtained.

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